Maxwell's Equations Test III

	Differential Form	Integral Form
Gauss's Law	$\nabla\cdot\vec{D}=\rho_v$	$\oint_S \vec{D}\cdot d\vec{S}=Q$
Faraday's Law	$\nabla\times\vec{E}=-\frac{\partial\vec{B}}{\partial t}$	$\oint_C \vec{E}d\vec{l}=-\int_S\frac{\partial\vec{B}}{\partial t}\cdot d\vec{S}$
Gauss's Law for Magnetism	$\nabla\cdot\vec{B}=0$	$\oint_S \vec{B}\cdot d\vec{S}=0$
Ampere's Law	$\nabla\times\vec{H}=\vec{J}+\frac{\partial\vec{D}}{\partial t}$	$\oint_C \vec{H}d\vec{l}=\int_S\left(\vec{J}+\frac{\partial\vec{D}}{\partial t}\right)\cdot d\vec{S}$

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Boundary Conditions for Electromagnetics

Field Components	General Form	Medium 1: Dielectric Medium 2: Dielectric	Medium1: Dielectric Medium 2: Conductor	
Tangential E	$\hat{n}_2\times(\vec{E}_1-\vec{E}_2)=0$	$E_{1t}=E_{2t}$	$E_{1t}=E_{2t}=0$	
Normal D	$\hat{n}_2\cdot(\vec{D}_1-\vec{D}_2)=\rho_s$	$D_{1n}-D_{2n}=\rho_s$	$D_{1n}=\rho_s$	$D_{2n}=0$
Tangential H	$\hat{n}_2\times(\vec{H}_1-\vec{H}_2)=J_s$	$H_{1t}=H_{2t}$	$H_{1t}=J_s$	$H_{2t}=0$
Normal B	$\hat{n}_2\cdot(\vec{B}_1-\vec{B}_2)=0$	$B_{1n}=B_{2n}$	$B_{1n}=B_{2n}=0$	

$$\vec{D}=\varepsilon\vec{E}=\varepsilon_0\varepsilon_r\vec{E}=\varepsilon_0(1+\chi_e)\vec{E} \qquad \vec{D}=\varepsilon_0\vec{E}+\vec{P}$$

$$\vec{B}=\mu\vec{H}=\mu_0\mu_r\vec{H}=\mu_0(1+\chi_m)\vec{H} \qquad \vec{B}=\mu_0(\vec{H}+\vec{M})$$

$$\frac{\partial\rho_v}{dt}+\frac{\sigma}{\varepsilon}\rho_v=0 \qquad \rho_v(t)=\rho_{v_0}e^{-(\sigma/\varepsilon)t}=\rho_{v_0}e^{-t/\tau_r}$$

$$V_{emf}=V_{emf}^{motional}+V_{emf}^{transformer}=-N\frac{d\Phi}{dt}=-N\frac{d}{dt}\int_S\vec{B}d\vec{S}$$

$$V_{emf}^{m}=\oint_C(\vec{u}\times\vec{B})\cdot d\vec{l} \qquad \nabla\cdot\vec{J}=-\frac{\partial\rho_v}{\partial t}$$

$$\nabla\times\tilde{H}=j\omega\varepsilon\tilde{E} \quad or \quad \tilde{E}=\frac{1}{j\omega\varepsilon}\nabla\times\tilde{H}$$

$$\nabla\times\tilde{E}=-j\omega\mu\tilde{H} \quad or \quad \tilde{H}=-\frac{1}{j\omega\mu}\nabla\times\tilde{E}$$

$$V(\vec{R},t)=\frac{1}{4\pi\varepsilon}\int_{v'}\frac{\rho_v(\vec{R}_i,t-R'/u_p)}{\vec{R}'}dv' \qquad \vec{B}=\hat{\phi}\frac{\mu_0 I}{2\pi r}$$

$$\vec{A}(\vec{R},t)=\frac{\mu}{4\pi}\int_{v'}\frac{\vec{J}(\vec{R}_i,t-R'/u_p)}{\vec{R}'}dv' \qquad Z_{in}=\left(\frac{N_1}{N_2}\right)^2 Z_L$$

$$V_{emf}=V_{emf}^{tr}+\vec{V}_{emf}^{m}=\oint_C\vec{E}\cdot d\vec{l}=-\int_S\frac{\partial\vec{B}}{\partial t}\cdot d\vec{s}+\oint_C(\vec{u}\times\vec{B})\cdot d\vec{l}$$

$$R=\frac{d}{\sigma A}$$

$$\vec{E}=-\nabla V-\frac{\partial\vec{A}}{\partial t} \qquad \eta=\frac{\omega\mu}{k}=\sqrt{\frac{\mu}{\varepsilon}}=\frac{\eta_0}{\sqrt{\varepsilon_r}}\Rightarrow\eta_0\approx120\pi$$

$$\vec{B}=\nabla\times\vec{A} \qquad \vec{u}=\hat{\phi}\omega r$$

$$\frac{d^2\tilde{E}_x}{dz^2}+k^2\tilde{E}_x=0 \qquad \frac{d^2\tilde{E}_y}{dz^2}+k^2\tilde{E}_y=0 \qquad \tilde{E}_z=0$$

$$\frac{d^2\tilde{H}_x}{dz^2}+k^2\tilde{H}_x=0 \qquad \frac{d^2\tilde{H}_y}{dz^2}+k^2\tilde{H}_y=0 \qquad \tilde{H}_z=0$$

$$E(z,t)=\Re e\left[\tilde{E}(z)e^{j\omega t}\right]=\hat{x}\left|E_{x0}^{+}\right|\cos(\omega t-kz+\Phi^{+})$$

$$H(z,t)=\Re e\left[\tilde{H}(z)e^{j\omega t}\right]=\hat{y}\frac{\left|E_{x0}^{+}\right|}{\eta}\cos(\omega t-kz+\Phi^{+})$$

$$u_p=\frac{\omega}{k}=\frac{\omega}{\omega\sqrt{\mu\varepsilon}}=\frac{1}{\sqrt{\mu\varepsilon}}$$

$$\lambda=\frac{2\pi}{k}=\frac{u_p}{f} \qquad S_{av}^{i}=\frac{\left|E_0^i\right|^2}{2\eta_1}\hat{z} \qquad S=\frac{1+|\Gamma|}{1-|\Gamma|}$$

$$S_{av}^{r}=|\Gamma|^2 S_{av}^{i}(-\hat{z}) \qquad S_{av}^{t}=|\tau|^2\frac{\left|E_0^i\right|^2}{2\eta_2}\hat{z}$$

$$\tilde{H}=\frac{1}{\eta}\hat{k}\times\tilde{E} \qquad \tilde{E}=-\eta\hat{k}\times\tilde{H}$$

$$\Gamma_{\parallel}=\frac{E_{\parallel0}^{r}}{E_{\parallel0}^{i}}=\frac{\eta_2\cos\theta_t-\eta_1\cos\theta_i}{\eta_2\cos\theta_t+\eta_1\cos\theta_i}$$

$$\tau_{\parallel}=\frac{E_{\parallel0}^{t}}{E_{\parallel0}^{i}}=\frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_t+\eta_1\cos\theta_i}$$

$$\tau_{\parallel}=(1+\Gamma_{\parallel})\frac{\cos\theta_i}{\cos\theta_t}$$

$$\lambda=\frac{\lambda_0}{\sqrt{\varepsilon_0}}=\frac{c}{f\sqrt{\varepsilon_r}} \qquad R_{dc}=\frac{l}{\sigma A}$$

$$c=3\times10^8 \quad m/s \qquad \eta_0=120\pi \quad \Omega \qquad R_{ac}=\frac{l}{\sigma w\delta_s}$$

$$E(z,t)=\Re e\left[\tilde{E}(z)e^{j\omega t}\right]=\hat{x}a_x\cos(\omega t-kz)+\hat{y}a_y\cos(\omega t-kz+\delta)$$

$$\left|\vec{E}(z,t)\right|=\left[a_x^2\cos^2(\omega t-kz)+a_y^2\cos^2(\omega t-kz+\delta)\right]^{1/2}$$

$$\psi(z,t)=\tan^{-1}\left(\frac{E_y(z,t)}{E_x(z,t)}\right)$$

$$\Gamma_{\perp}=\frac{E_{\perp0}^{r}}{E_{\perp0}^{i}}=\frac{\eta_2\cos\theta_i-\eta_1\cos\theta_t}{\eta_2\cos\theta_i+\eta_1\cos\theta_t}$$

$$\tau_{\perp}=\frac{E_{\perp0}^{t}}{E_{\perp0}^{i}}=\frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_i+\eta_1\cos\theta_t}$$

$$\tau_{\perp}=1+\Gamma_{\perp}$$

$$\vec{S}_{av}=\hat{z}\frac{1}{2\eta}\left(\left|E_{x0}\right|^2+\left|E_{y0}\right|^2\right)=\hat{z}\frac{\left|\tilde{E}\right|^2}{2\eta} \quad (W/m^2)$$

$$\varepsilon_r=\left(\frac{c}{u_p}\right)^2 \qquad k_2=\sqrt{\frac{\varepsilon_2}{\varepsilon_1}}k_1 \qquad E^r=\Gamma E^i$$

$$\eta=\eta_0/\sqrt{\varepsilon_r}$$

$$\Gamma_{\parallel}=\frac{-(\varepsilon_2/\varepsilon_1)\cos\theta_i+\sqrt{(\varepsilon_2/\varepsilon_1)-\sin^2\theta_i}}{(\varepsilon_2/\varepsilon_1)\cos\theta_i+\sqrt{(\varepsilon_2/\varepsilon_1)-\sin^2\theta_i}}$$

$$\frac{\varepsilon''}{\varepsilon'}=\frac{\sigma}{\omega\varepsilon}=\frac{\sigma}{2\pi f\varepsilon_r\varepsilon_0}$$

$$R_{\parallel}=\left|\Gamma_{\parallel}\right|^2$$

$$T_{\parallel}=1-R_{\parallel}$$

$$\tilde{E}_{\perp}^{i} = \hat{y}E_{\perp 0}^{i}e^{-jk_1(x\sin\theta_i + z\cos\theta_i)}$$

$$\tilde{H}_{\perp}^{i} = (-\hat{x}\cos\theta_i + \hat{z}\sin\theta_i)\frac{E_{\perp 0}^{i}}{\eta_1}e^{-jk_1(x\sin\theta_i + z\cos\theta_i)}$$

$$\tan 2\gamma = (\tan 2\psi_0)\cos\delta \quad -\frac{\pi}{2} \le \gamma \le \frac{\pi}{2}$$

$$\sin 2\chi = (\sin 2\psi_0)\sin\delta \quad -\pi/4 \le \chi \le \pi/4$$

$$\tilde{E}_{\perp}^{r} = \hat{y}E_{\perp 0}^{r}e^{-jk_1 x_r} = \hat{y}E_{\perp 0}^{r}e^{-jk_1(x\sin\theta_r - z\cos\theta_r)}$$

$$\tan\psi_0 = \frac{a_y}{a_x} \quad 0 \le \psi_0 \le \frac{\pi}{2}$$

$$\tilde{H}_{\perp}^{r} = \hat{y}_r\frac{E_{\perp 0}^{r}}{\eta_1}e^{-jk_1 x_r} = (\hat{x}\cos\theta_r + \hat{z}\sin\theta_r)\frac{E_{\perp 0}^{r}}{\eta_1}e^{-jk_1(x\sin\theta_r - z\cos\theta_r)}$$

$$\tilde{E}_{\perp}^{t} = \hat{y}E_{\perp 0}^{t}e^{-jk_2 x_t} = \hat{y}E_{\perp 0}^{t}e^{-jk_2(x\sin\theta_t + z\cos\theta_t)}$$

$$\tilde{H}_{\perp}^{t} = \hat{y}_t\frac{E_{\perp 0}^{t}}{\eta_2}e^{-jk_2 x_t} = (-\hat{x}\cos\theta_t + \hat{z}\sin\theta_t)\frac{E_{\perp 0}^{t}}{\eta_2}e^{-jk_2(x\sin\theta_t + z\cos\theta_t)}$$

$$E(z,t) = \Re e\left[\tilde{E}(z)e^{j\omega t}\right] = \hat{x}a_x\cos(\omega t - kz) + \hat{y}a_y\cos(\omega t - kz + \delta)$$

$$\tilde{E}_{\parallel}^{i} = \hat{y}_i E_{\parallel 0}^{i}e^{-jk_1 x_i} = (\hat{x}\cos\theta_i - \hat{z}\sin\theta_i)E_{\parallel 0}^{i}e^{-jk_1(x\sin\theta_i + z\cos\theta_i)}$$

$$\tilde{H}_{\parallel}^{i} = \hat{y}\frac{E_{\parallel 0}^{i}}{\eta_1}e^{-jk_1 x_i} = \hat{y}\frac{E_{\parallel 0}^{i}}{\eta_1}e^{-jk_1(x\sin\theta_i + z\cos\theta_i)}$$

$$R' = R_1' + R_2'' = \frac{R_s}{2\pi}\left(\frac{1}{a} + \frac{1}{b}\right)$$

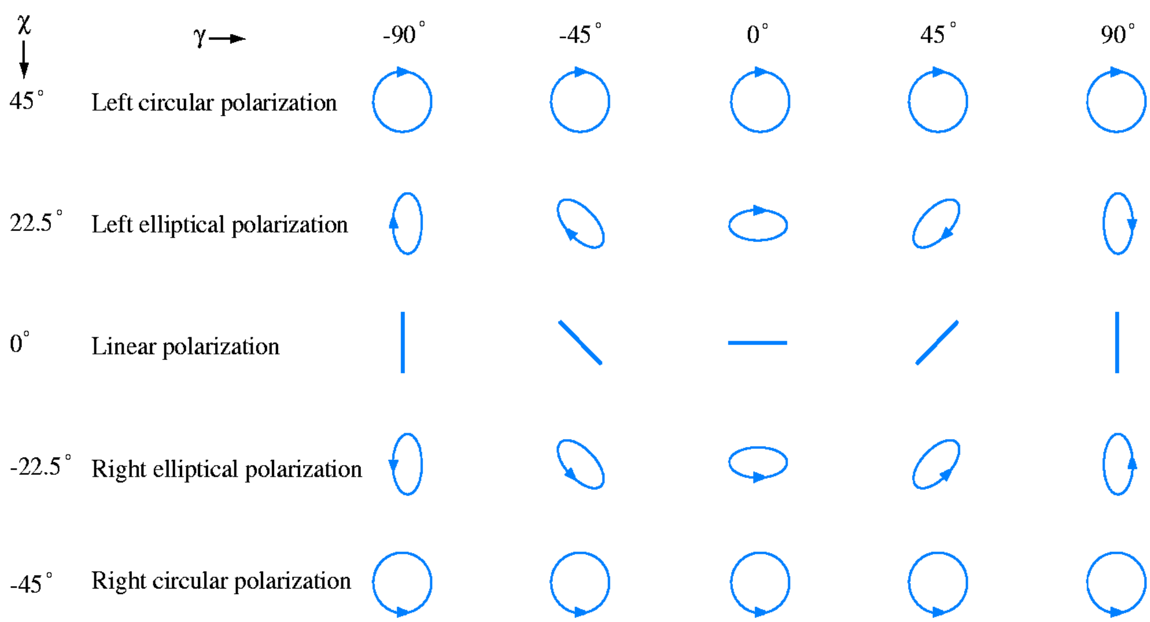
$$\tilde{E}_{\parallel}^{r} = \hat{y}_r E_{\parallel 0}^{r}e^{-jk_1 x_r} = (\hat{x}\cos\theta_r + \hat{z}\sin\theta_r)E_{\parallel 0}^{r}e^{-jk_1(x\sin\theta_r - z\cos\theta_r)}$$

$$\tilde{H}_{\parallel}^{r} = -\hat{y}\frac{E_{\parallel 0}^{r}}{\eta_1}e^{-jk_1 x_r} = -\hat{y}\frac{E_{\parallel 0}^{r}}{\eta_1}e^{-jk_1(x\sin\theta_r + z\cos\theta_r)}$$

$$\tilde{E}_{\parallel}^{t} = \hat{y}_t E_{\parallel 0}^{t}e^{-jk_2 x_t} = (\hat{x}\cos\theta_t - \hat{z}\sin\theta_t)E_{\parallel 0}^{t}e^{-jk_2(x\sin\theta_t + z\cos\theta_t)}$$

$$\tilde{H}_{\parallel}^{t} = \hat{y}\frac{E_{\parallel 0}^{t}}{\eta_2}e^{-jk_2 x_t} = \hat{y}\frac{E_{\parallel 0}^{t}}{\eta_2}e^{-jk_2(x\sin\theta_t + z\cos\theta_t)}$$

$$\delta_s = \frac{1}{\alpha} = \frac{1}{\sqrt{\pi f\mu\sigma}}$$



	Any Medium	Lossless Medium (σ=0)	Low-Loss Medium (ε"/ε'<<1)	Good Conductor (ε"/ε'>>1)	Units
α=	$\omega\left\{\frac{\mu\varepsilon'}{2}\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right]\right\}^{1/2}$	0	$\frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\pi f\mu\sigma}$	(Np/m)
β=	$\omega\left\{\frac{\mu\varepsilon'}{2}\left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}+1\right]\right\}^{1/2}$	$\omega\sqrt{\mu\varepsilon}$	$\omega\sqrt{\mu\varepsilon}$	$\sqrt{\pi f\mu\sigma}$	(rad/m)
η_c=	$\sqrt{\frac{\mu}{\varepsilon'}}\left(1-j\frac{\varepsilon''}{\varepsilon'}\right)^{-1/2}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$\sqrt{\frac{\mu}{\varepsilon}}$	$(1+j)\frac{\alpha}{\sigma}$	(Ω)
u_p=	ω/β	$1/\sqrt{\mu\varepsilon}$	$1/\sqrt{\mu\varepsilon}$	$\sqrt{4\pi f/\mu\sigma}$	(m/s)
λ=	$2\pi/\beta = u_p/f$	u_p/f	u_p/f	u_p/f	(m)

$$\nabla^2\tilde{E}-\gamma^2\tilde{E}=0$$

$$\varepsilon_{complex}\triangleq\varepsilon-j\frac{\sigma}{\omega}$$

$$\gamma^2=-k^2$$

$$\eta_c=|\eta_c|e^{j\theta_\eta}$$

$$E(z,t)=\Re e\left[\tilde{E}(z)e^{j\omega t}\right]=\hat{x}\left|E_{x0}^{+}\right|\cos(\omega t-kz+\Phi^{+})$$

$$H(z,t)=\Re e\left[\tilde{H}(z)e^{j\omega t}\right]=\hat{y}\frac{\left|E_{x0}^{+}\right|}{\eta}\cos(\omega t-kz+\Phi^{+})$$

$$\gamma^2=-\omega^2\mu\varepsilon_{complex}=-\omega^2\mu(\varepsilon'-j\varepsilon'')=-\omega^2\mu(\varepsilon-j\frac{\sigma}{\omega})$$

$$\gamma=\alpha+j\beta\Rightarrow\gamma^2=(\alpha+j\beta)^2=(\alpha^2-\beta^2)+j2\alpha\beta$$

$$\vec{S}_{av}=\frac{1}{2}\Re e\left[\tilde{E}\times\tilde{H}^{*}\right]=\frac{\hat{z}\left(\left|E_{x0}\right|^2+\left|E_{y0}\right|^2\right)}{2}e^{-2\alpha z}\Re e\left(\frac{1}{\eta_c^{*}}\right)$$

$$\Gamma=\frac{\eta_{c_2}-\eta_{c_1}}{\eta_{c_2}+\eta_{c_1}}\qquad\alpha^2-\beta^2=-\omega^2\mu\varepsilon'=-\frac{\omega^2}{c^2}\varepsilon_r'$$

$$\tau=1+\Gamma=\frac{2\eta_{c_2}}{\eta_{c_2}+\eta_{c_1}}\qquad 2\alpha\beta=\omega^2\mu\varepsilon''=\frac{\omega^2}{c^2}\varepsilon_r''$$

$$\frac{\sin\theta_t}{\sin\theta_i}=\frac{u_{p_2}}{u_{p_1}}=\frac{n_1}{n_2}=\sqrt{\frac{\mu_1\varepsilon_1}{\mu_2\varepsilon_2}}=\sqrt{\frac{\mu_{r_1}\varepsilon_{r_1}}{\mu_{r_2}\varepsilon_{r_1}}}=\sqrt{\frac{\varepsilon_{r_1}}{\varepsilon_{r_2}}}=\frac{\eta_2}{\eta_1}$$

$$\Omega_p=\iint_{4\pi}F(\theta,\phi)d\Omega\quad(sr)\qquad D=\frac{4\pi}{\Omega_p}\cong\frac{4\pi}{\beta_{xz}\beta_{yz}}$$

$$\tilde{H}_\phi=\frac{I_0lk^2}{4\pi}e^{-jkR}\left[\frac{j}{kR}+\frac{1}{(kR)^2}\right]\sin\theta$$

$$\vec{S}_{av}(z)=\hat{z}\frac{|E_0|^2}{2|\eta_c|}e^{-2\alpha z}\cos\Theta_\eta\quad(W/m^2)\qquad Z_s=\frac{1+j}{\sigma\delta_s}=R_s+j\omega L_s$$

$$\tilde{E}_R=\frac{2I_0lk^2}{4\pi}\eta_0e^{-jkR}\left[\frac{1}{(kR)^2}-\frac{j}{(kR)^3}\right]\cos\theta$$

$$R_s=\frac{1}{\sigma\delta_s}=\sqrt{\frac{\pi f\mu}{\sigma}}\qquad\delta_s=\frac{1}{\alpha}=\frac{1}{\sqrt{\pi f\mu\sigma}}$$

$$\tilde{E}_\theta=\frac{I_0lk^2}{4\pi}\eta_0e^{-jkR}\left[\frac{j}{kR}+\frac{1}{(kR)^2}-\frac{j}{(kR)^3}\right]\sin\theta$$

$$L_s=\frac{1}{\omega\sigma\delta_s}=\frac{1}{2}\sqrt{\frac{\mu}{\pi f\sigma}}\qquad\xi_tA_t=\xi_tD_t\lambda^2/4\pi=G_t\lambda^2/4\pi$$

$$S_r=G_tS_{iso}=\xi_tD_tS_{iso}=\frac{\xi_tD_tP_t}{4\pi R^2}$$

$$P_{rec}=\xi_rP_{int}$$

$$P_{int}=S_rA_r=\frac{\xi_tA_tA_rP_t}{\lambda^2R^2}$$

$$F(\theta,\phi)=\frac{S(R,\theta,\phi)}{S_{max}}\qquad P_n=KT_{sys}B$$

$$S_r=\frac{\xi_tA_tP_t}{\lambda^2R^2}$$

$$\frac{P_{rec}}{P_t}=\frac{\xi_t\xi_rA_tA_r}{\lambda^2R^2}=G_tG_r\left(\frac{\lambda}{4\pi R}\right)^2$$

$$\frac{P_{rec}}{P_t}=G_tG_r\left(\frac{\lambda}{4\pi R}\right)^2F_t(\theta_t,\phi_t)F_r(\theta_r,\phi_r)$$

$$\varepsilon_0=8.85\times10^{-12}\quad F/m$$

$$\mu_0=4\pi\times10^{-7}\quad H/m$$

$$k=1.38\times10^{-23}\quad J/K$$

Maxwell's Equations

$$\nabla \cdot \vec{D} = \rho$$
$$\nabla \cdot \vec{B} = 0$$
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$
$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

Assumptions:

linear, isotropic, and homogeneous medium:

$$\vec{D} = \varepsilon \vec{E}$$
$$\vec{B} = \mu \vec{H}$$

Time variation is a sinusoidal function:

$$\vec{E}(x, y, z; t) = \Re e\left[\tilde{E}(x, y, z)e^{j\omega t}\right]$$

$$\nabla \cdot \tilde{E} = \tilde{\rho}_v / \varepsilon$$
$$\nabla \times \tilde{E} = -j\omega\mu\tilde{H}$$
$$\nabla \cdot \tilde{H} = 0$$
$$\nabla \times \tilde{H} = \tilde{J} + j\omega\varepsilon\tilde{E}$$

Charge free medium

$$\tilde{\rho}_v = 0$$

$$\nabla \cdot \tilde{E} = 0$$
$$\nabla \times \tilde{E} = -j\omega\mu\tilde{H}$$
$$\nabla \cdot \tilde{H} = 0$$
$$\nabla \times \tilde{H} = \tilde{J} + j\omega\varepsilon\tilde{E}$$

$$\tilde{J} = \sigma\tilde{E}$$

$$\varepsilon_{complex} \triangleq \varepsilon - j\frac{\sigma}{\omega}$$

$$\nabla \cdot \tilde{E} = 0$$
$$\nabla \times \tilde{E} = -j\omega\mu\tilde{H}$$
$$\nabla \cdot \tilde{H} = 0$$
$$\nabla \times \tilde{H} = j\omega\varepsilon_{complex}\tilde{E}$$

Propagation Constant

$$\gamma^2 = -\omega^2 \mu\varepsilon_{complex}$$

Wave Equation

$$\nabla^2\tilde{E} - \gamma^2\tilde{E} = 0$$
$$\nabla^2\tilde{H} - \gamma^2\tilde{H} = 0$$

lossless medium

$$\sigma = 0$$

$$\varepsilon_{complex} \triangleq \varepsilon - j\frac{\sigma}{\omega}$$

Wavenumber

$$k^2 = -\gamma^2 = \omega^2\mu\varepsilon$$

$$\nabla^2\tilde{E} + k^2\tilde{E} = 0$$
$$\nabla^2\tilde{H} + k^2\tilde{H} = 0$$

$$\frac{d^2\tilde{E}_x}{dz^2} + k^2\tilde{E}_x = 0$$
$$\frac{d^2\tilde{E}_y}{dz^2} + k^2\tilde{E}_y = 0$$
$$\tilde{E}_z = 0$$

$$\frac{d^2\tilde{H}_x}{dz^2} + k^2\tilde{H}_x = 0$$
$$\frac{d^2\tilde{H}_y}{dz^2} + k^2\tilde{H}_y = 0$$
$$\tilde{H}_z = 0$$

Plane Wave
Cartesian Coordinate
Propagation in z-direction

Solution:

$$\vec{E}(z,t) = \Re e\left[\tilde{E}(z)e^{j\omega t}\right] = \hat{x}a_x\cos(\omega t - kz + \delta_x) + \hat{y}a_y\cos(\omega t - kz + \delta_y)$$

$$\tilde{H} = \frac{1}{\eta}\hat{z}\times\tilde{E}$$

Intrinsic Impedance

$$\eta = \sqrt{\frac{\mu}{\varepsilon}}$$

$$\frac{\omega}{k} = u_p = \frac{1}{\sqrt{\mu\varepsilon}} = \lambda f$$

$$\vec{H}(z,t) = \Re e\left[\tilde{H}(z)e^{j\omega t}\right] = \hat{x}b_x\cos(\omega t - kz + \delta_x) + \hat{y}b_y\cos(\omega t - kz + \delta_y)$$